

What is claimed is:

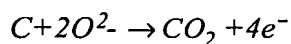
1. A direct-electrochemical-oxidation fuel cell for generating electrical energy from a solid-state organic fuel comprising:

a cathode provided with an electrochemical-reduction catalyst that promotes formation of oxygen ions from an oxygen-containing source at the cathode;

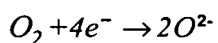
an anode provided with an electrochemical-oxidation catalyst that promotes direct electrochemical oxidation of the solid-state organic fuel in the presence of the oxygen ions to produce electrical energy; and

a solid-oxide electrolyte disposed to transmit the oxygen ions from the cathode to the anode, wherein

direct electrochemical oxidation at the anode occurs according to the reaction:



2. The fuel cell according to claim 1, wherein formation of the oxygen ions at the cathode proceeds according to the reaction:



3. The fuel cell according to claim 1, wherein the solid-state organic fuel is coal, graphite, biomass or a combination thereof.

4. The fuel cell according to claim 3, wherein the biomass is selected from a group consisting of peat, rice hulls, and corn husks.

5. The fuel cell according to claim 1, wherein the direct electrochemical oxidation at said anode produces a product comprising a CO<sub>2</sub> concentration of at least 50 mol %.

6. The fuel cell according to claim 1, wherein the electrochemical-reduction catalyst is lanthanum strontium manganese oxide.

7. The fuel cell according to claim 1, wherein the electrochemical-reduction catalyst is selected from the group consisting of LSF; LSCF; SSC;  $\text{YBa}_2\text{Cu}_3\text{O}_y$ , wherein  $y$  is an integer having values within a range of 7-9;  $\text{La}_{0.99}\text{MnO}_3$ ;  $\text{LaMnO}_3$ ;  $\text{La}_x\text{Sr}_y\text{Mn}_3$  and  $\text{La}_x\text{Ca}_y\text{MnO}_3$ , wherein  $x$  is a number having values within a range of 0.6-0.95, and  $y$  is a number having values within a range of 0.1-0.4.

8. The fuel cell according to claim 1, wherein the electrochemical-reduction catalyst is selected from the group consisting of material having a general formula of  $\text{A}_x\text{B}_y\text{CO}_3$ , wherein  $A$  is selected from the group consisting of La, Gd, Sm, Nd, Pr, Tb and Sr,  $B$  is selected from the group consisting of Sr, Ce, and Co,  $x$  is a number having values within a range of 0.6-0.94, and  $y$  is a number having values within a range of 0.1-0.4.

9. The fuel cell according to claim 1, wherein the electrochemical-oxidation catalyst provided to the anode includes platinum.

10. The fuel cell according to claim 1, wherein the electrochemical-oxidation catalyst includes Rhenium.

11. The fuel cell according to claim 10, wherein the electrochemical-electrochemical oxidation catalyst is Re-NiO/YSZ.

12. The fuel cell according to claim 10, wherein the electrochemical-oxidation catalyst is Cu oxide-Pt.

13. The fuel cell according to claim 1, wherein the solid-oxide electrolyte is selected from the group consisting of doped oxides of Bi, Zr, Hf, Th, and Ce with either alkaline earth oxides such as CaO or MgO, or rare-earth oxides such as  $\text{Sc}_2\text{O}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ , and the like. For example, embodiments of the present invention include a solid-oxide electrolyte 18 comprising at least one of  $\text{Bi}_2\text{O}_3$ ,  $(\text{Bi}_{2-0.75}\text{Y}_{0.75})_{0.25}$ ,  $\text{BaTh}_{0.9}\text{Gd}_{0.1}\text{O}_3$ ,  $\text{La}_{0.8}\text{Sr}_{0.2}\text{Ga}_{0.8}\text{Mg}_{0.2}\text{O}_3$ ,  $(\text{Ce}_{2-0.8}\text{Gd}_{0.8})_{0.2}$ ,  $(\text{Zr}_{2-0.9}\text{Sc}_{0.9})_{0.1}$ ,  $(\text{ZrO}_2)_{0.9}(\text{Y}_2\text{O}_3)_{0.1}$ ,  $(\text{ZrO}_2)_{0.87}(\text{CaO})_{0.13}$ ,  $(\text{La}_{2-0.95}\text{Sr}_{0.95})_{0.05}$ .

14. The fuel cell according to claim 1, wherein the solid-oxide electrolyte is selected from the group consisting of yttrium-stabilized zirconium and bismuth oxide.

15. The fuel cell according to claim 1 further comprising a housing that encloses the anode for receiving the solid-state organic fuel.

16. The fuel cell according to claim 15 further comprising feed passage through which the solid-state organic fuel can be inserted into the housing.

17. The fuel cell according to claim 1, wherein the electrochemical oxidation that occurs at the anode produces a product comprising a  $\text{NO}_x$  concentration of less than 5 mol %, wherein x is an integer within a range of 1 to 3.

18. The fuel cell according to claim 17, wherein the fuel cell has a maximum operating temperature of about  $1200^\circ\text{C}$ .

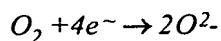
19. The fuel cell according to claim 1, wherein the direct electrochemical oxidation that occurs at the cathode results in a product comprising a CO concentration that is less than 10 mol %.
20. The fuel cell according to claim 19, wherein the fuel cell has a maximum operating temperature of about 1200°C.
21. The fuel cell according to claim 1, wherein the fuel cell produces an electrical current of at least 100 mA/cm<sup>2</sup> for a period of time lasting at least 48 hours.
22. The fuel cell according to claim 1, wherein the fuel-conversion efficiency of the fuel cell is at least 30 mol % at 950°C.
23. A direct-electrochemical-electrochemical oxidation fuel cell for generating electrical energy from a solid-state organic fuel comprising:
- a cathode provided with an electrochemical-reduction catalyst that promotes the formation of ions from an ion source at the cathode;
  - a anode provided with an electrochemical-oxidation catalyst that includes a sulfur-resistant material and promotes electrochemical oxidation of the solid-state organic fuel in the presence of the ions formed at the cathode to produce electrical energy; and
  - a solid-oxide electrolyte disposed to transmit the ions from the cathode to the anode.
24. The fuel cell according to claim 23, wherein the sulfur-resistant material includes at least one of Re, Mn and Mo.

25. The fuel cell according to claim 24, wherein the sulfur-resistant material is selected from the group consisting of Re-NiO/YSZ, Cu oxide-Pt.

26. The fuel cell according to claim 23, wherein the electrochemical-reduction catalyst is lanthanum strontium manganese oxide.

27. The fuel cell according to claim 23, wherein the electrochemical-reduction catalyst is selected from the group consisting of LSF; LSCF; SSC;  $\text{YBa}_2\text{Cu}_3\text{O}_y$ , wherein y is an integer having values within a range of 7-9;  $\text{La}_{0.99}\text{MnO}_3$ ;  $\text{LaMnO}_3$ ;  $\text{La}_x\text{Sr}_y\text{Mn}_3$  and  $\text{La}_x\text{Ca}_y\text{MnO}_3$ , wherein x is a number having values within a range of 0.6-0.95, and y is a number having values within a range of 0.1-0.4.

28. The fuel cell according to claim 23, wherein the ions formed at the cathode are oxygen ions formed according to the reaction:



29. The fuel cell according to claim 23, wherein the solid-state organic fuel is coal, graphite, biomass, polymers or a combination thereof.

30. The fuel cell according to claim 29, wherein the biomass is selected from a group consisting of peat, rice hulls, and corn husks.

31. The fuel cell according to claim 23, wherein the solid-oxide electrolyte is selected from the group consisting of doped oxides of Bi, Zr, Hf, Th, and Ce with either alkaline earth oxides such as CaO or MgO, or rare-earth oxides such as  $\text{Sc}_2\text{O}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ , and the like. For example, embodiments of the present invention include a solid-oxide electrolyte 18 comprising at least one of  $\text{Bi}_2\text{O}_2$ ,  $(\text{Bi}_2\text{O}_7)_{0.75}(\text{Y}_2\text{O}_3)_{0.25}$ ,  $\text{BaTh}_{0.9}\text{Gd}_{0.1}\text{O}_3$ ,  $\text{La}_{0.8}\text{Sr}_{0.2}\text{Ga}_{0.8}\text{Mg}_{0.2}\text{O}_{3.5}$ ,  $(\text{Ce}_2)_{0.8}(\text{GdO}_{0.5})_{0.2}$ ,  $(\text{ZrO}_2)_{0.9}(\text{Sc}_2\text{O}_3)_{0.1}$ ,  $(\text{ZrO}_2)_{0.9}(\text{Y}_2\text{O}_3)_{0.1}$ ,  $(\text{ZrO}_2)_{0.57}(\text{CaO})_{0.43}$ ,  $(\text{La}_2\text{O}_3)_{0.95}(\text{SrO})_{0.05}$ .

32. The fuel cell according to claim 31, wherein the solid-oxide electrolyte is selected from the group consisting of yttrium-stabilized zirconium and bismuth oxide.

33. The fuel cell according to claim 23, wherein electrochemical oxidation of the solid-state organic fuel at the anode produces a product having a  $\text{CO}_2$  concentration of at least 50 mol %.

34. The fuel cell according to claim 33, wherein the fuel cell has a maximum operating temperature that is less than  $1200^\circ\text{C}$ .

35. The fuel cell according to claim 23, wherein electrochemical oxidation of the solid-state organic fuel at the anode produces a product having a  $\text{NO}_x$  concentration that is less than 0.1 mol %, wherein x represents integers ranging from 1 to 3.

36. The fuel cell according to claim 23, wherein the electrochemical-oxidation catalyst is selected from the group consisting of a noble metal, group VIII metal/metal oxide, such as Pt, Cu, Ag, Au, Pd, Ni, oxides of the aforementioned sulfur-resistant materials, oxides of Ce, Cr, Fe, and Pb, combinations thereof, multiple oxides, combinations including one or more of the aforementioned metals, Cu oxide-Pt, and Re-NiO/YSZ, wherein the electrochemical-oxidation

catalysts including non-noble metals also include a sulfur-resistant substance selected from the group consisting of Re, Mn, Mo, Ag, Cu, and Au.

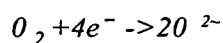
37. A method of generating electric power from a solid-state organic fuel, said method comprising the steps of:

forming oxygen ions from an oxygen-containing source at a cathode;

transmitting the oxygen ions formed at the cathode to an anode with a solid-oxide electrolyte; and

catalyzing a reaction of the oxygen ions with the solid-state organic fuel to directly oxidize the solid-state organic fuel at the anode to produce a product comprising CO<sub>2</sub> and electrical energy.

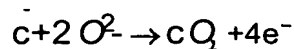
38. The fuel cell according to claim 37, wherein the step of forming oxygen ions comprises the step catalyzing a reaction at the cathode with a lanthanum strontium manganese oxide catalyst according to the formula:



39. The fuel cell according to claim 37, wherein the step of catalyzing the reaction of the oxygen ions further comprises the steps of:

providing a catalyst comprising a sulfur-resistant material to the anode; and

directly electrochemically oxidizing the solid-state organic fuel according to the reaction:



40. A method of generating electric energy from a solid-state organic fuel, said method comprising the steps of:

establishing an ionic-communication channel between a cathode and an anode with a solid-oxide electrolyte

providing an electrochemical-oxidation catalyst that includes a sulfur-resistant material to the anode, wherein the electrochemical-oxidation catalyst promotes direct electrochemical oxidation of the solid-state organic fuel at the anode to produce a product comprising  $\text{CO}_2$  and electrical energy;

providing an electrochemical-reduction catalyst to the cathode, wherein the electrochemical-reduction catalyst promotes the production of oxygen ions from an oxygen-containing source; and

forming a conductive channel to conduct the electrical energy away from the cathode.